*Indian J. Phys.* **70B** (6), 443–451 (1996)

**IJP B**
- an international journal

# Study of thermal and electrical conductivities in the ionosphere

R Misra and P K Das

P. K. College, Contai, Midnapore-721 401, West Bengal, India

*Received 30 January 1996, accepted 26 September 1996*

**Abstract** : Considering the electrons, ions and neutrals moving freely to some extent in the ionosphere, thermal ($K$) and electrical ($\sigma$) conductivities have been studied at different altitudes using data from MSIS-83 and USSA-76 models. It is seen that $K$ and $\sigma$ are not linearly related. Also at any altitude, $K_e$ ($K$ for electrons) has the highest value while $K_i$ ($K$ for ions) is lowest with $K_n$ ($K$ for neutrals) lying between them, although neutral density is highest in the altitude range 90 to 220 km. Attempts have been made to explain the above findings.

**Keywords** : Ionosphere, thermal and electrical conductivity, viscous dissipation, random encounter, quasi-neutrality

**PACS Nos.** : 92 60 -e, 94 20.-y

## 1. Introduction

The ionosphere may be considered as a quasi-neutral medium where the particles are in random motion. The movement of the ions and electrons may be controlled by applied or induced electric and magnetic fields while that of all particles may be affected by wind only.

Again, the ionosphere becomes heated by absorbing EUV from sun and other stellar bodies, infrared emissions, viscous dissipation and the effects associated with geomagnetic activities amongst which EUV is the main contributor [1]. This influences the motion of the particles. Due to the motion of ionised particles, electric current flows in certain restricted directions and the motion of all particles makes the heat flux to flow. The magnitude of both will depend upon the properties of the region under consideration. In other words, the electric flux depends on the rate of diffusion of the ions and electrons and the heat flux depends on that of ions, electrons as well as the neutrals. But the electrons on account of their smallest mass, will have greater velocity contributing mainly to the flow of flux in both cases. Thus, the conductivities of a region may be attributed mainly to the motion of electrons.

The electrical conductivity has been studied [2] in the ionospheric *E*-region at low latitudes considering the electric field and neutral winds and the results have been compared with observations at Arecibo (18.15° N, 66.20° W), Thumba (8°32′N, 76°51′E) and SHAR (14.0° N, 80.0° E). The effect of the ionospheric conductivity on the longitudinal structure of the *F*-region equatorial anomaly, above the magnetic equator at African and West Asian regions, has been studied [3]. Recently, ionospheric conductivities have also been studied by few others [4–6].

In the present work, thermal and electrical conductivities have been studied for two models (MSIS–83 and USSA–76) in the altitude range of 90 to 220 km, as the data in this region are available. It has been assumed that the properties of a region remain constant over a small horizontal slab. The contributions to the conductivities (both thermal and electrical) by the electrons, ions and neutral particles have been considered. To consider the effects of conductivities, the following restrictive assumptions are made.

(i) Loss of energy due to particle motion is less than that due to random encounters amongst them [7].

(ii) The electric field and temperature gradients are weak [8].

(iii) For quasi-neutrality and constant pressure, the diffusion velocities are negligibly small [9].

(iv) Temperature gradient exists only in vertical direction, along which the conductivities have been considered.

The present study will give us an idea about the diffusion of ions, electrons and neutrals in an ionospheric region. Also the flow of flux could be estimated from such studies. From the values of $K$ and $\sigma$, an idea about the thermal and electrical behaviour of the medium could be made. This will also lead to a knowledge about the nature of the medium (ionospheric region). The estimation of $K$ may give an idea about the heat conduction through the region concerned and the ionospheric heating by UV, X-rays *etc* coming from the Sun and other sources.

## 2. Theoretical considerations

Although electrons are the main contributors to the conductivities, yet to study the transport phenomenon in a partially ionised medium like ionosphere, the interactions of electrons, ions and neutrals have to be considered for greater accuracy.

For simplicity, taking the electrons and singly ionized ions into account for a plasma, the following expressions for coefficient of thermal conductivity have been used for electrons ($K_e$) and ions ($K_i$) respectively [10].

$$K_e = \frac{75}{4\sqrt{\pi}(8+13\sqrt{2})} \cdot \frac{k(kT_e)^{5/2}}{m_e^{1/2} e^4 \log \Lambda} \tag{1}$$

and
$$K_i = \frac{75}{32\sqrt{\pi}} \frac{k(kT_i)^{5/2}}{m_i^{1/2} e^4 \log \Lambda}, \tag{2}$$

where $k$ = Boltzman constant, $T_e$ = electron temperature, $e$ = charge of an electron, $m_e$ = mass of an electron, $T_i$ = ion temperature of the region concerned (here $T_i = T_e = T$ approximately), $m_i$ = mass of ion and $\Lambda = \frac{3(kT)^{3/2}}{2e^3(N\pi)^{1/2}}$, $N$ = electron or ion density of the region considered.

The following formula for thermal conductivity for neutral particles ($K_n$) has been used [1]

$$K_n = \sum \beta_j \frac{n_j}{n} T^{\alpha_j}, \tag{3}$$

where $n_j$ is the concentration of the $j$-th constituent and $n$ is the total neutral number density. The coefficients $\alpha_j$ and $\beta_j$ are given in Reference [1] as obtained from the literature [11,12].

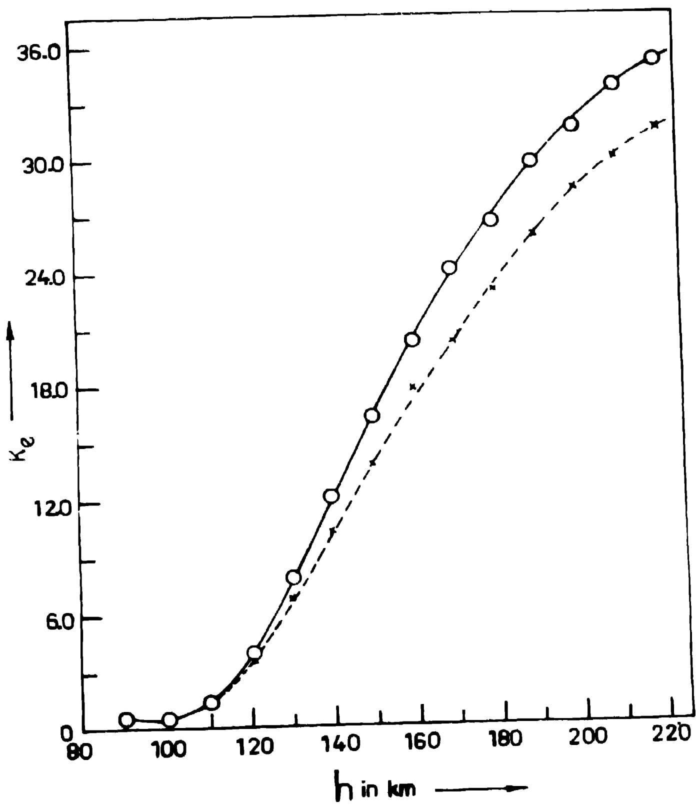


**Figure 1.** Altitude variation of thermal conductivity for electrons ($K_e$), solid curve for MSIS-83 and dotted curve for USSA-76 models.

In absence of wave propagation and external electric and magnetic fields, the electrical conductivity of a region depends mainly on interaction of electrons with other

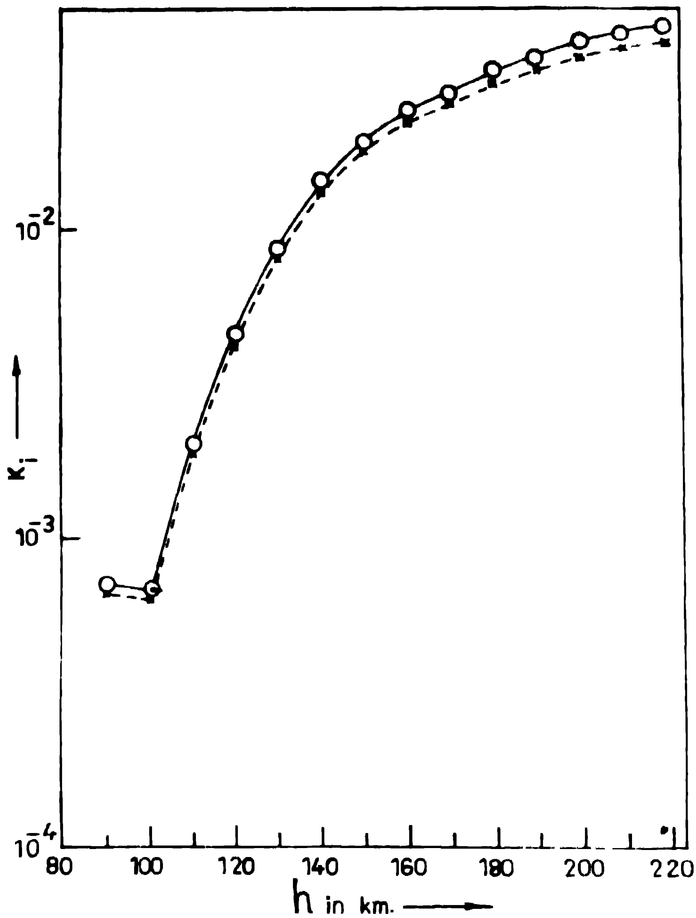


**Figure 2.** Altitude variation of thermal conductivity for ions ($K_i$), solid curve for MSIS–83 and dotted curve for USSA–76 models

particles and on the property of the medium. Under these circumstances, the effective conductivity is Pedersen conductivity [13,14], the expression for which is given by

$$\sigma = Ne^2\left[\frac{\nu_e}{m_e(\nu_e^2+\omega_e^2)} + \frac{\nu_i}{m_i(\nu_i^2+\omega_i^2)}\right], \tag{4}$$

where $\nu_e$ and $\nu_i$ are the collision frequencies of electrons and ions respectively and $\omega_e$ and $\omega_i$ are the respective gyro-frequencies.

Computation of $K_e$, $K_i$, $K_n$ and $\sigma$ using eqs. (1), (2), (3) and (4) respectively, have been made using data for the models MSIS-83 and USSA-76. [15].

## 3. Discussions

It is obvious that the density of neutral particles is higher at lower altitudes having negative altitude gradient. From the available data, it is revealed that the density of charged particles increases upto an altitude of 150 km above which it is almost constant. At any altitude, although the density of electrons and ions will be same, the mobility of electrons will be higher than that of ions.

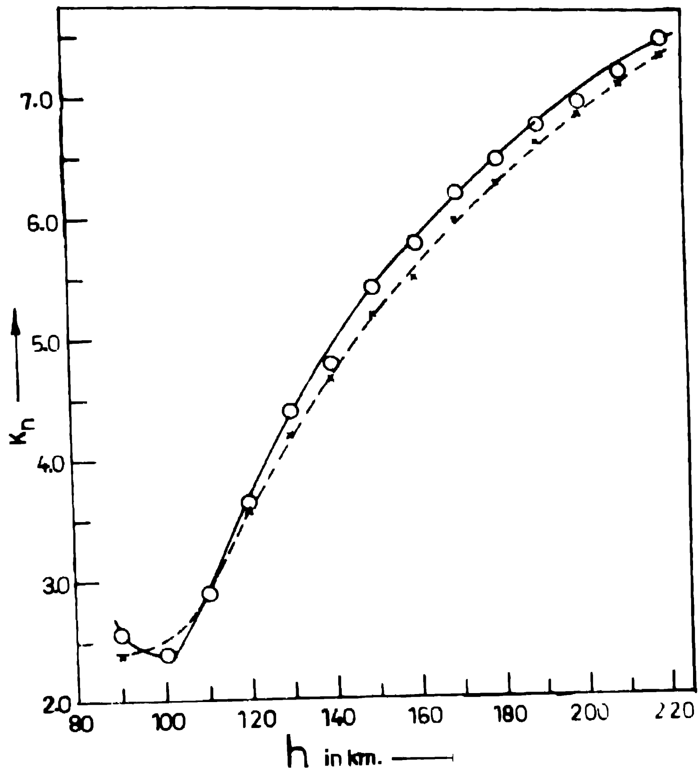


**Figure 3.** Altitude variation of thermal conductivity for neutral particles ($K_n$), solid curve for MSIS-83 and dotted curve for USSA-76 models

From Figures 1 to 4, it is observed that the values of conductivities attain minimum at about 100 km. At this altitude, the coupling effect between $E$ and $F$ regions is strong producing absorption of energy (absorption of electrical energy is higher than thermal energy), thereby reducing $K$ and $\sigma$. Above 130 km, due to dynamo action, $K$ increases largely in all cases but $\sigma$ decreases.

It is also observed that at any altitude, the value of $K_i$ is lowest due to their heavier mass and hence low mobility. At about 120 km, the values of $K_e$ and $K_n$ are approximately equal. Below 120 km, $K_n$ is higher than $K_e$. This is due to the fact that at lower altitudes neutral particle density is higher than that of the others. Again above 120 km, $K_e$ is higher than $K_n$ as neutral particle density decreases with increasing altitude.

At any altitude above 120 km :

(i) $K_i$ is lowest although the ions and electrons have the same density. It is because of the low mobility of the former,

(ii) $K_e$ is highest since the mobility of electrons is highest though it has less density than neutrals,

(iii) $K_n$ has intermediate values because the neutral particles have greater density than electrons and the former has less mobility.

So far as neutral particles are concerned, the contributions of $N_2$, $O_2$, O, He and Ar are considerable amongst which those due to $N_2$ and O are main [15]. From the available

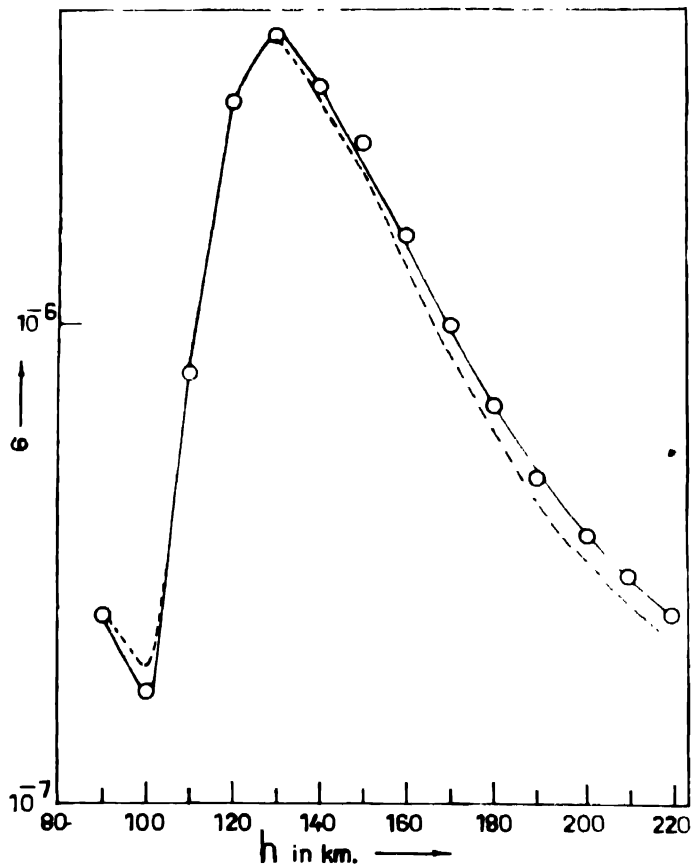


**Figure 4.** Altitude variation of electrical conductivity ($\sigma$), solid curve for MSIS-83 and dotted curve for USSA-76 models.

data, it is found that though the total density of the neutral particles decreases with the increase in altitude,

(a) the contribution of $N_2$ increases with the increase in altitude,

(b) the contribution of $O_2$ decreases with increase in altitude and becomes negligible at about 170 km,

(c) the contribution of O increases with altitude,

(d) the contribution of He is the lowest increasing with altitude,

(e) the contribution of Ar decreases with altitude and becomes negligibly small at about 130 km,

(f) with increasing altitude, the contribution of $N_2$ relative to O decreases and *vice-versa*.

Figure 5 shows altitude variation of total $K$ (= $K_e + K_i + K_n$). The nature of the graph can be explained from above statements.

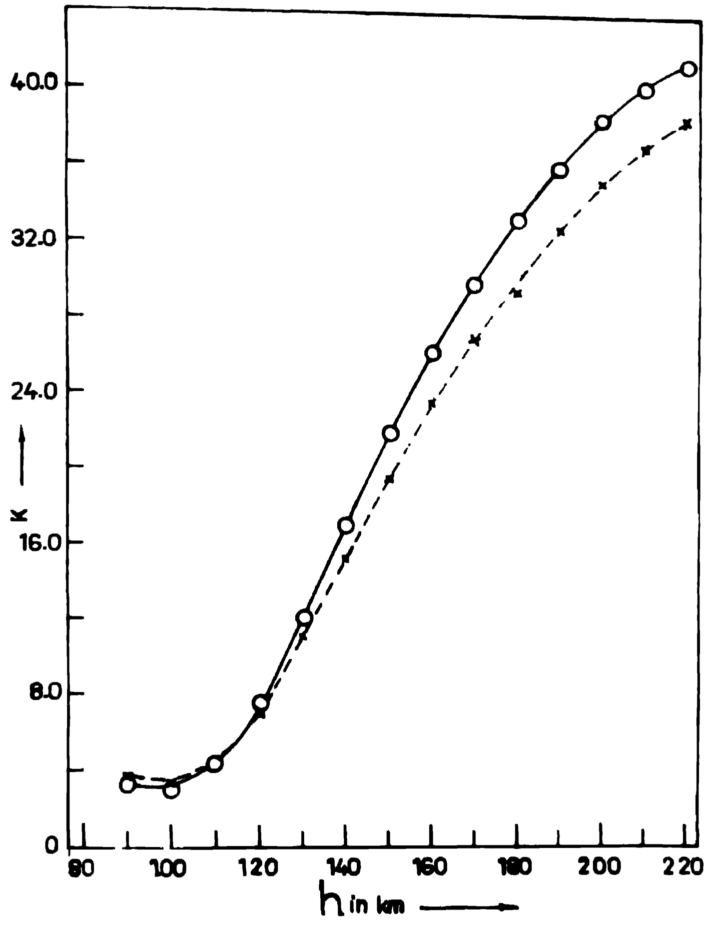


**Figure 5.** Altitude variation of total thermal conductivity $K$ (= $K_e + K_i + K_n$), solid curve for MSIS–83 and dotted curve for USSA-76 models.

Figure 6 shows the variation of $K / \sigma T$ with altitude. Here, a crest is obtained at about 100 km and a trough near about 120 km. The crest may be due to strong coupling between $E$ and $F$ regions where absorption of both types of energy takes place but that of electrical energy is more, thereby increasing $K/\sigma T$. At about 120 km, due to moderate density of all types of particles, $N$ and $\nu_e$ have large values. This increases $\sigma$ largely thereby decreasing $K/\sigma T$ rapidly.

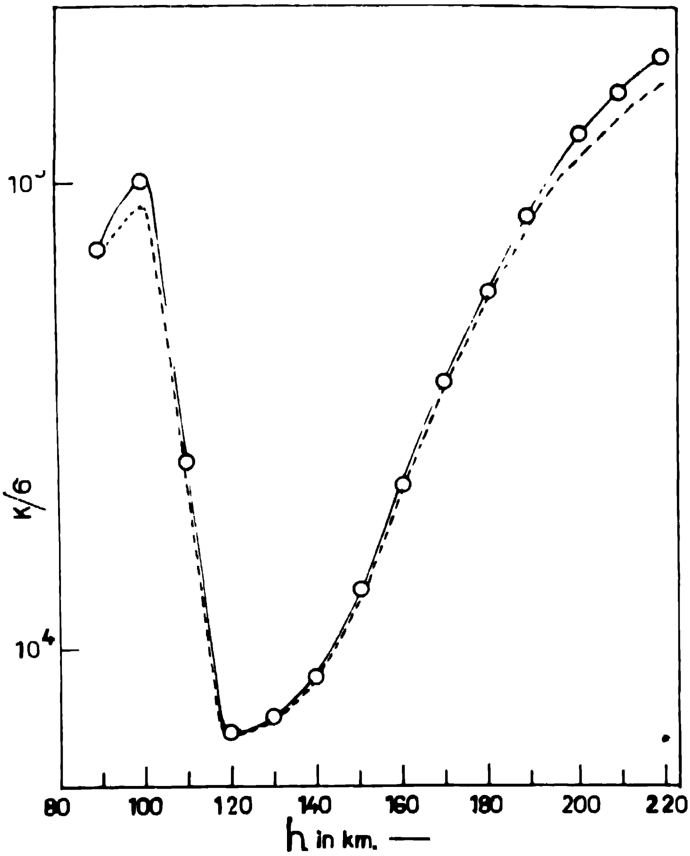


**Figure 6.** Altitude variation of $K/\sigma T$, solid curve for MSIS-83 and dotted curve for USSA-76 models.

Errors may come in this work due to the following reasons :

(a) The assumption that ionospheric particles move quite freely, is partially true,

(b) The consideration that the factors governing the properties of the ionosphere are constant over a small slab, is an approximation.

(c) The computation of conductivities considering singly charged ions only, is for simplicity. Actually, the ionosphere is more complicated.

(d) The restriction that the properties of the ionospheric slab vary along the vertical direction only, is not always true.

**References**


[1] J M Straus, S P Creekmore, R M Harris, B K Ching and Y T Chiu *J. Atmos Terr. Phys.* **37** 1245 (1975)

[2] R P Singhal *J. Atmos Terr. Phys.* **53** 949 (1991)

[3] M Aydogdu *J. Atmos Terr Phys.* **54** 179 (1992)

[4] V L Saveliev *Planet. Space Sci.* (U.K ) **39** 1133 (1991)

[5] V V Denisenko and S S Zamay *Geomagn. Aeron.* **31** 428 (1991)

[6] G Kirchengast and R Leitinger *Ann Geophys., Atmos. Hydrospheres Space Sci.* (France) **10** 577 (1992)

[7] D Pines and D Bohm *Phys. Rev* **85** 338 (1952)

[8] K Spitzer and R Harm *Phys. Rev.* **89** 977 (1953)

[9] W E Meador (Jr.) and L D Staton *Phys. Fluids* **8** 1694 (1965)

[10] R W Schunk *Planet. Space Sci.* **23** 437 (1975)

[11] A Dalgarno and F J Smith *Planet. Space Sci* **9** 1 (1962)

[12] S Chapman and T G Cowling *The Mathematical Theory of Nonuniform Gases* (London . Cambridge University Press) (1952)

[13] W G Baker and D F Martin *Phil Trans. Roy. Soc.* **246A** 281 (1953)

[14] R G Whitten and I G Poppoff *Physics of the Lower Ionosphere* (Englewood Cliffs, New Jersey . Prentice Hall) p 257 (1965)

[15] A E Hedin *J. Geophys. Res.* **88** 10170 (1983)